Convective influence in the tropical near-tropopause region diagnosed from *in-situ* measurements of water vapor isotopic composition

E.J. Moyer[1], T.F. Hanisco[1], D.S. Sayres[1], J. St. Clair[1], E.M. Weinstock[1], J.B. Smith[1], R.A. Lockwood[1], M. Bolot[3], S.C. Wofsy[2], S.Y. Park[2], B.C. Daube[2], L. Pfister[4], J.G. Anderson[1]

[1]Dept. of Chemistry and Chemical Biology, Harvard Univ. [2]Dept. of Earth and Planetary Sciences, Harvard Univ. [3]Ecole Normale Supèrieure, Paris, [4]NASA-Ames Research Center

A new convective tracer: δD

Measurement of water isotopic composition (the ratio of HDO or $H_2{}^{18}O$ to H_2O) can be used to diagnose convective influence in the UT/LS. Convective transport of water vapor produces characteristic isotopic signatures. Water vapor in convective updrafts becomes isotopically light because condensation preferentially removes the heavy isotopologues. Lofted convectice ice is a reservoir of heavy water, and evaporating ice in detraining clouds produces isotopic enhancement.

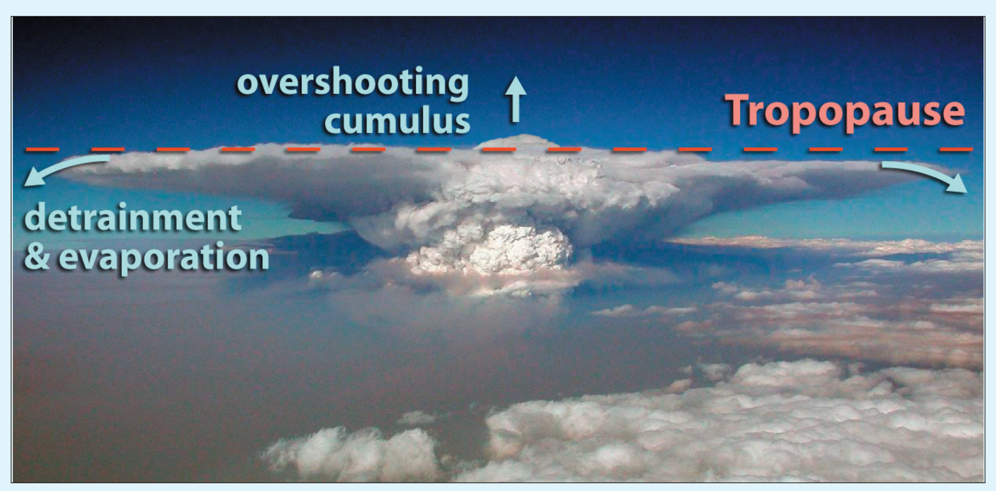
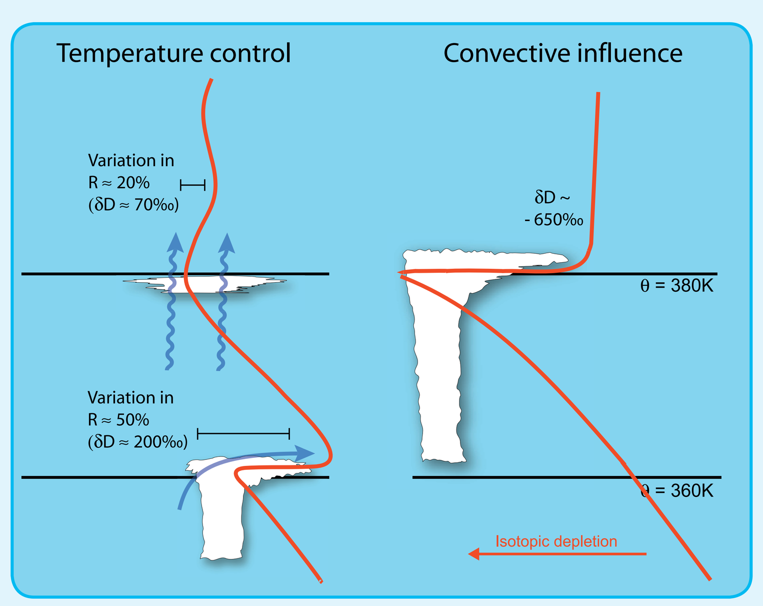


Figure 1: Tropical cumulus capillatus reaching the tropopause and overshooting above it. Detrainment of ice from these clouds can be a source of UT/LS water.

Isotopic profiles and water vapor control

Different mechanisms affecting UT/LS water have different expected isotopic effects.

If convection plays little role in the UT/LS water budget, convective detrainment & isotopic enhancement should cease near the base of the TTL (L cartoon). The TTL should then show progressive depletion with loss of water vapor.



If convection plays a strong role in either hydrating or dehydrating the UT/LS, the profile of water isotopic composition will be altered (R cartoon).

New instruments for isotopic measurements

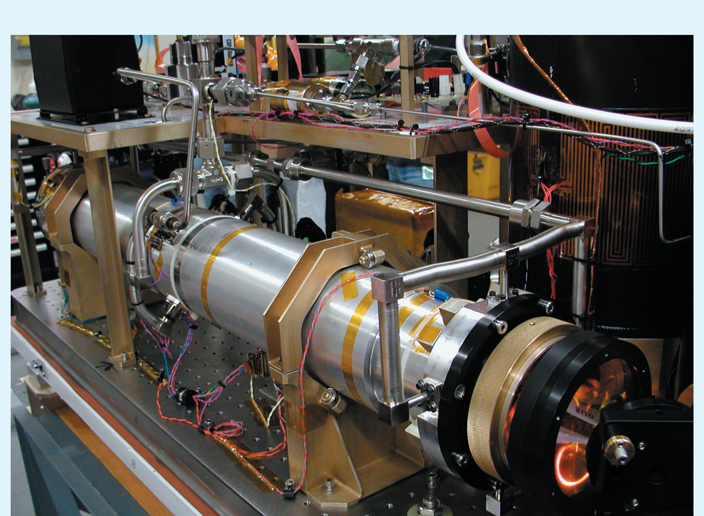


Figure 2: The Harvard ICOS Isotope Instrument on the laboratory bench with optics exposed. The absorption spectrometer has an effective pathlength of over 4 kilometers. The instrument is designed to fly on NASA's WB-57 research aircraft.

We show here results from a new instrument for the *in-situ* measurement of water vapor isotopes. The Harvard ICOS Isotope Instrument measures HDO, $H_2{}^{18}O$, H_2O, and CH_4, with a 1σ sensitivity of 30 per mil in 4 s. in the dry stratosphere.

Accuracy is a greater concern than precision. Ascents may show ca. 0.5 ppm contamination, which has isotopic consequences.

The Harvard Hoxotope Instrument flew with ICOS in 2005. It measures HDO and H_2O. It has slightly lower sensitivity but is more robust against contamination.

Profiles of δD across the tropopause show the transport history of water vapor

The CR-AVE and AVE-WIIF missions:

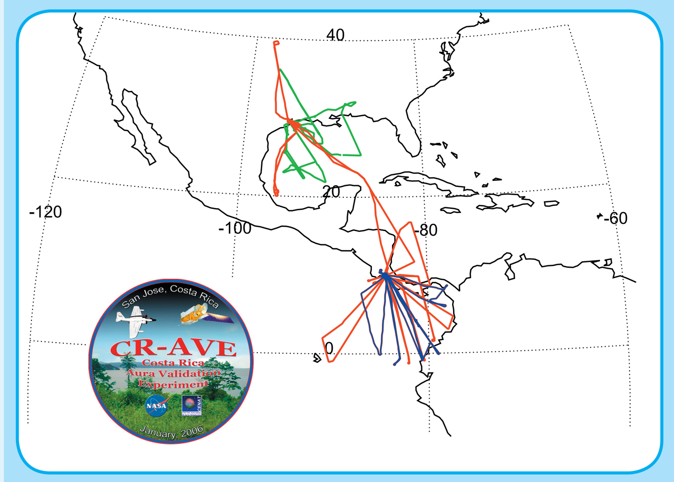


Figure 3: Flight paths on the 2005-2006 missions. Isotopic data are shown here from flights marked in green (AVE-WIIF) and blue (CR-AVE).

The Harvard ICOS Isotope Instrument has obtained measurements of UT/LS water vapor isotopes on missions in both midlatitudes (AVE-WIIF, Jun.-Jul. 2005) and tropics (CR-AVE, Jan-Feb. 2006). The instrument sampled conditions including recent convective outflow, remnants of convective towers overshooting the stratosphere, and near-tropopause cirrus with tropical tropopause temperatures below 182 K. The CR-AVE data represent the first *in-situ* water measurements obtained across the tropical tropopause.

Data from both midlatitudes and tropical flights show that:

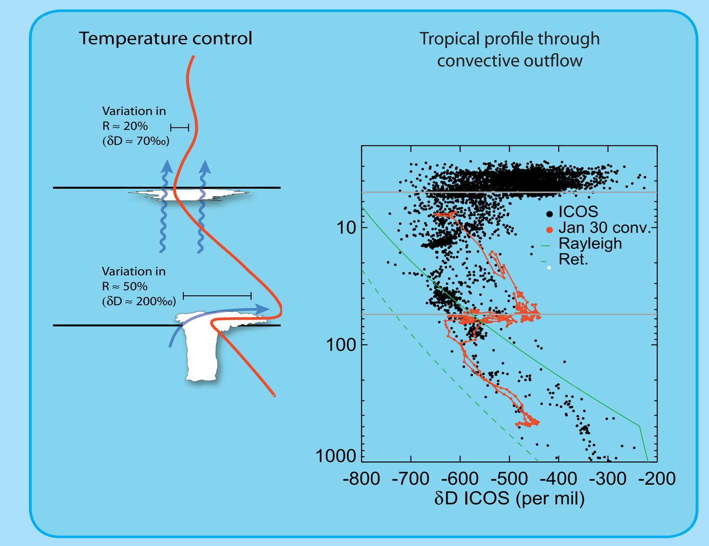
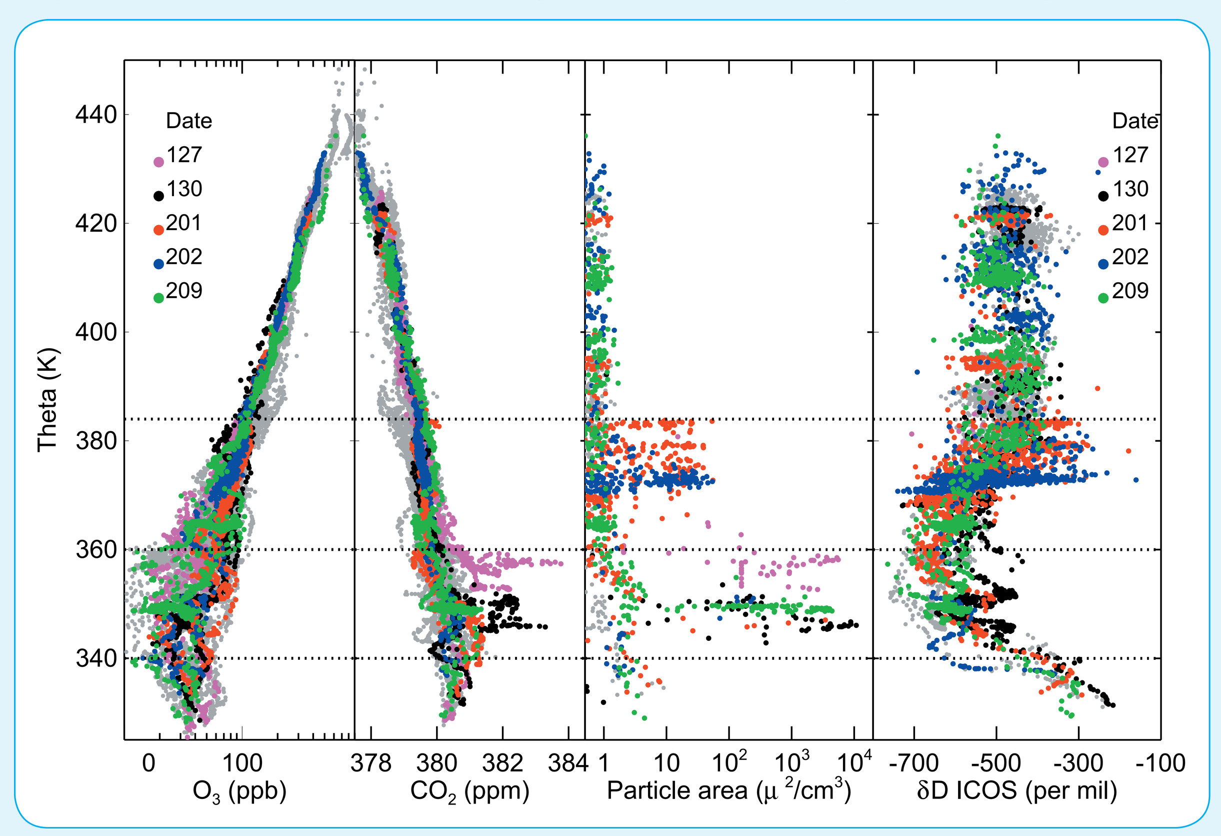


Figure 4: Flight through remnants of tropical convective system.

- Isotopic depletion within updraft cores does occur as Rayleigh theory predicts.
- Enhancement off the Rayleigh profiles is the result of evaporating convective ice.
- Both tropics and midlatitudes show enhancement in the UT/LS.
- Convective remnants well above the 380 K θ surface can be identified by their isotopic signatures.

Deep convection is evident during CR-AVE throughout the tropical near-tropopause region

Figure 5: Tracers measured during CR-AVE consistently show strong detrainment at the TTL base and weaker detrainment to well above the tropopause.



1) Data shown are for all CR-AVE for O_3 and CO_2. Particle area (from CAPS) and δD are shown for only the 2nd half of the mission. δD was not measured at low altitude on 0127. Contrail encounters have been removed from the dataset for clarity. 1 hour of ascents are pruned.

2) The WB-57 made 4 major transits through thick convective outflow at the base of the TTL. These outflows contain hundreds of ppm of water as ice and boundary-layer values of CO_2 and O_3. δD is enhanced above and below saturated outflows.

3) Convective ice is seen at altitudes up to 385 K. These higher outflows are presumably quite diffuse by the time the aircraft encounters them, and show only small anomalies in CO_2 and total water. δD clearly identifies them as convective rather than *in-situ* cirrus, however. Enhancements occur in supersaturated air.

4) δD profiles are nearly constant throughout the TTL region. They show no falloff as would be expected for gradual dessication by *in-situ* cirrus production.

AVE-WIIF shows that isotopic enhancement is produced by evaporating cloud ice

Flights during AVE-WIIF coincided with strong midlatitudes convection, with convective plumes detraining into extremely subsaturated surroundings.

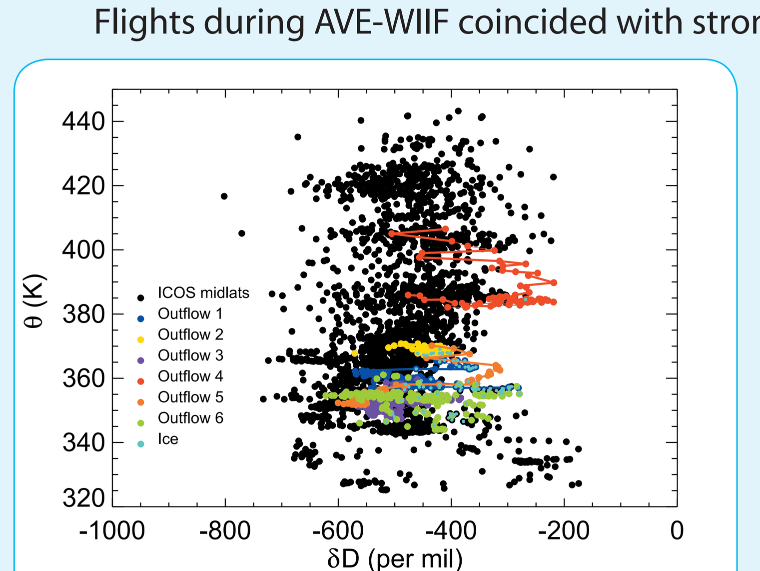


Figure 6: AVE-WIIF observations of anomalies in isotopic water associated with deep convective outflows. (identified by water and CO_2 anomalies). ICOS isotopic data on July 3 and 5 is calibrated using HOxotope profiles.

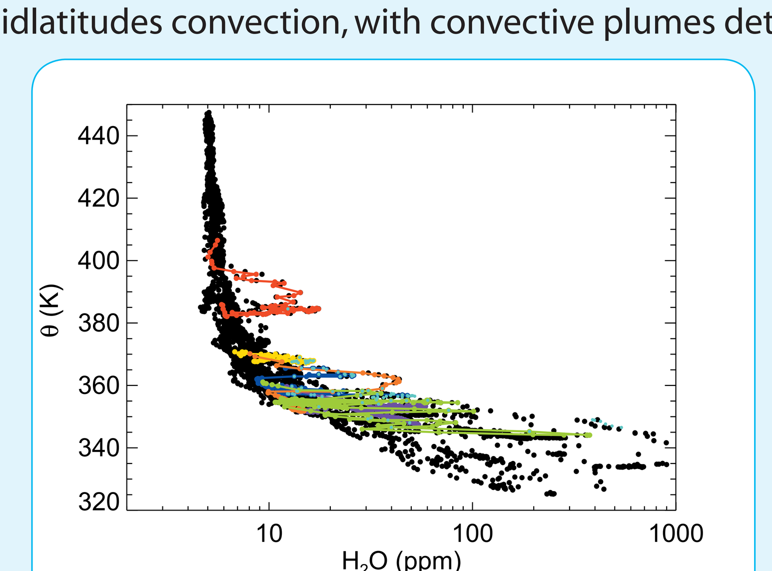


Figure 7: High water in convective outflows, extending up to 400 K θ. Background profiles have RH ~ 10-20%. Water vapor data are from the Harvard Ly-α instrument. Some higher δD is expected in wetter air; Fig. 8 shows these are anomalies.

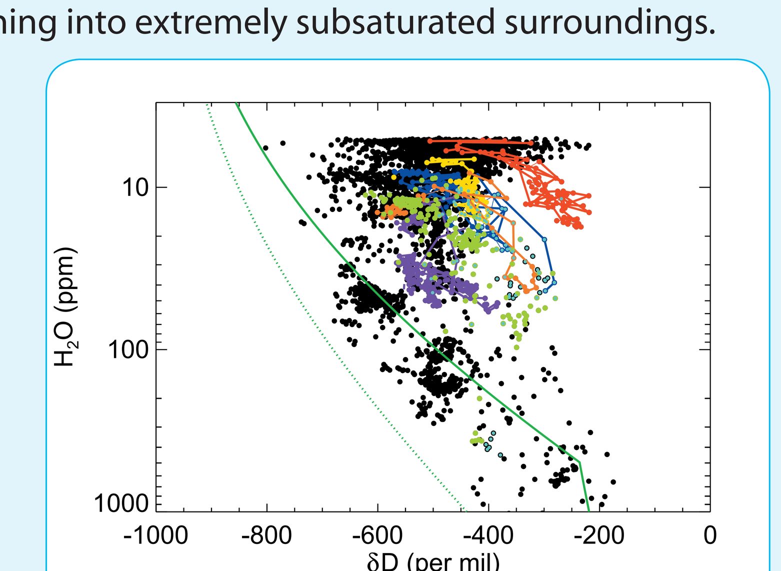


Figure 8: Plotting against water vapor shows that convective plumes are isotopically enhanced off the Rayleigh curve. This must result from mixing with evaporated ice. The individual plumes follow mixing lines.

Dehydration in the TTL is not simple

Figure 9: Water vapor and RH in the E. Pacific TTL. Water vapor falls off in this region, dropping a factor of 4 from TTL base to tropopause., but little if any of this is due to local dessication. Water falls off more slowly than Clausius-Clapeyron dictates; RH generally increases throughout the TTL from under- to supersaturation. High RH does not prompt in-situ cirrus formation. The highest RH observed is associated with convective cirrus, possibly because high RH allows ice particles to persist longer.

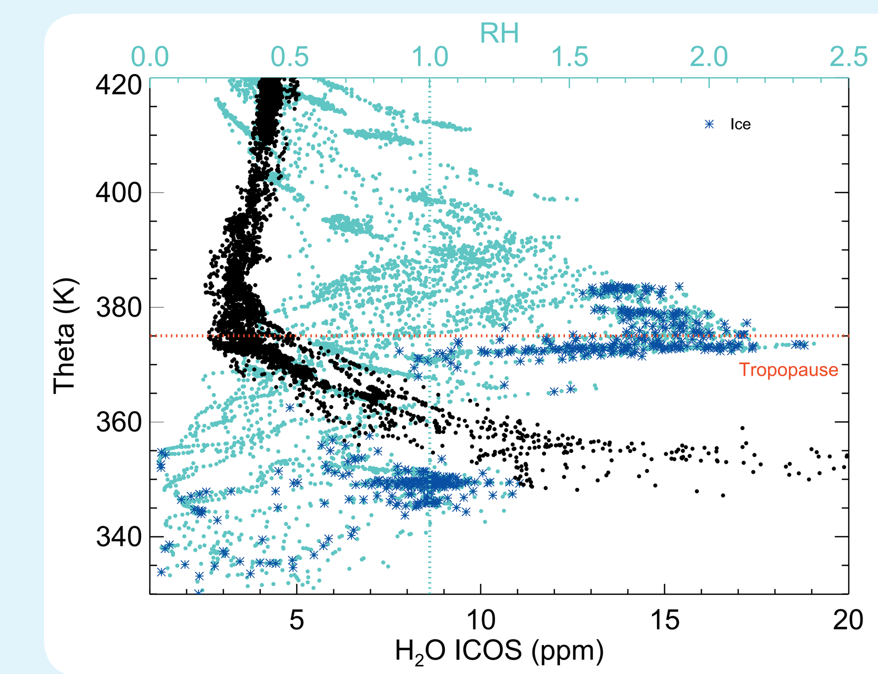
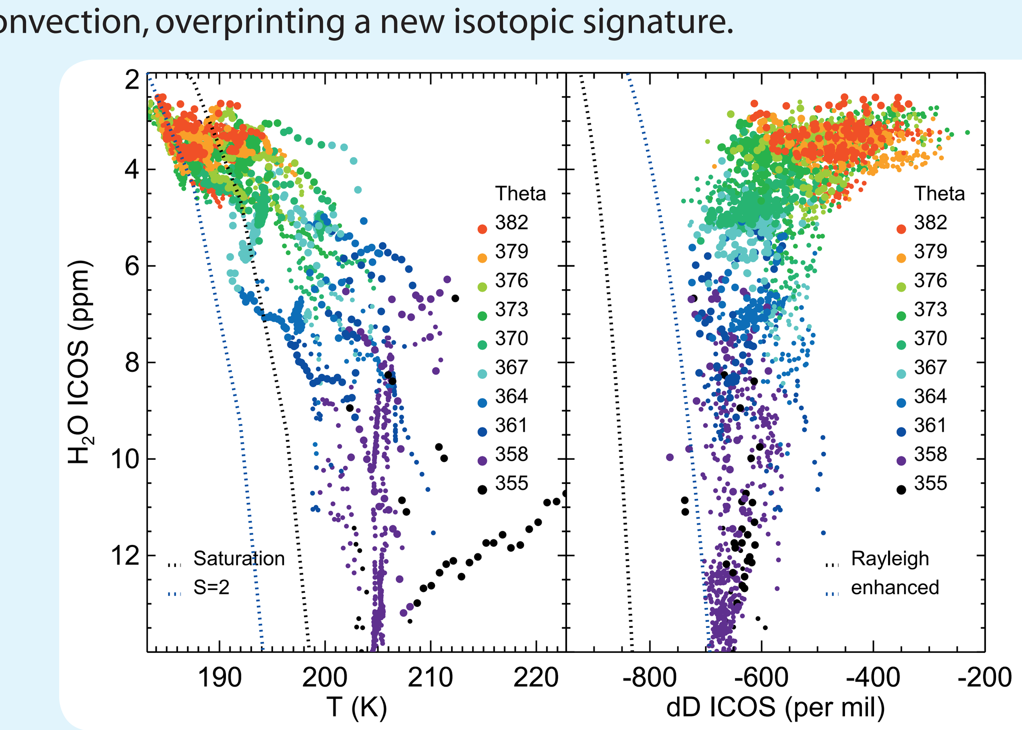


Figure 10 : δD does not support T-controlled dessication elsewhere. Correlation between CR-AVE TTL water and δD is weak (L). If dessication occured via *in-situ* cirrus formation in colder parts of the tropics, δD should still follow water vapor. Strong variations in water at a given local temperature (R) are often clearly due to convective outflow rather than distant air origins. Any *in-situ* dessication must be strongly modified by convection, overprinting a new isotopic signature.



Conclusions

Preliminary analysis of water isotopic data suggests:

- Convective detrainment occurs throughout the tropical TTL, though as expected the bulk of detrainment is at its base, near 360 K θ.
- Isotopic measurements are not consistent with dessication in gradual ascent. If any *in-situ* dessication occurs, it must be strongly modified by convective evaporation, overprinting a new isotopic signature.
- Convection at high altitudes seems to produce a disproportionate isotopic effect. This can be replicated readily with simple models.
- The local E. Pacific stratosphere is isotopically distinct from the TTL below.
- Midlatitudes and tropics are broadly consistent in showing detachment from Rayleigh in the upper troposphere.

References

[1] Moyer, E.J. et al. ``ATMOS stratospheric deuterated water and implications for troposphere-stratosphere transport." *Geophys. Rev. Lett.*, 23, 2385, 1996.

[2] Kuang, Z., G.C. Toon, P.O. Wennberg, and Y.L. Yung. ``Measured HDO/H_2O ratios across the tropical tropopause." *Geophys. Rev. Lett.*, 30, 1372, 2003.

[3] Webster, C.W. and A.J. Heymsfeld. ``Water Isotope Ratios D/H, $^{18}O/^{16}O$, $^{17}O/^{16}O$ in and out of clouds map dehydration pathways." *Science* 302, 1745, 2003.